Title: Preequilibrium Emission of Light Fragments in Spallation Reactions

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Precompound Emission of Light Fragments in Spallation Reactions

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Los Alamos National Laboratory

Why This Research Is Important

<u>Single Event Upsets (SEUs)</u>

- **October 2008, Airbus en route from Perth to Singapore[1]**

[1]Necia Grant Cooper, "The Invisible Neutron Threat", National Security Science Feb. 2012: 13.

- **Cold war satellite malfunctioned, detected nuclear missile launch[2]**

[2]Countdown to Zero, dir. Lucy Walker, perf. Graham Allison, James Baker III, DVD, Magnolia, 2010.

Why This Research Is Important, cont.

Also Important in

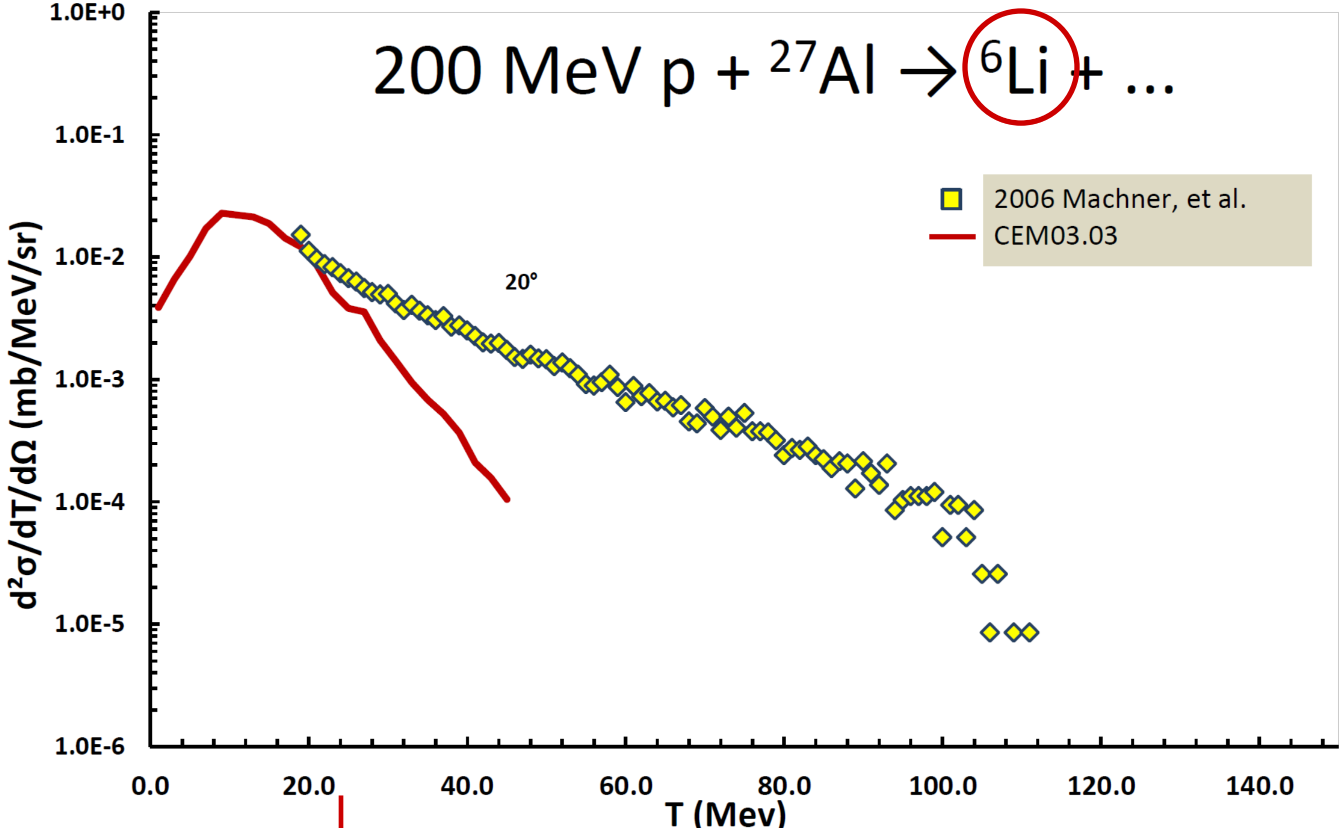
- Radiation Shielding
- Medical applications (proton therapy for cancer)
- Understanding better the mechanisms of nuclear reactions

The 2008-2010 IAEA Benchmark of Spallation Models

- Recommended considering preequilibrium emission (and maybe also coalescence production) of fragments heavier than ^{4}He [3,4]

- [3] S. G. Mashnik et al., "Second Advanced Workshop on Model Codes for Spallation Reactions", CEA-Saclay, France, 8-11 Feb 2010, LA-UR-10-00510.
- [4] S. Leray et al., "Results from the IAEA Benchmark of Spallation Models", Journal of the Korean Physical Society Vol. 59, No. 2 (2011), 791-796.

Current Capabilities of CEM03.03



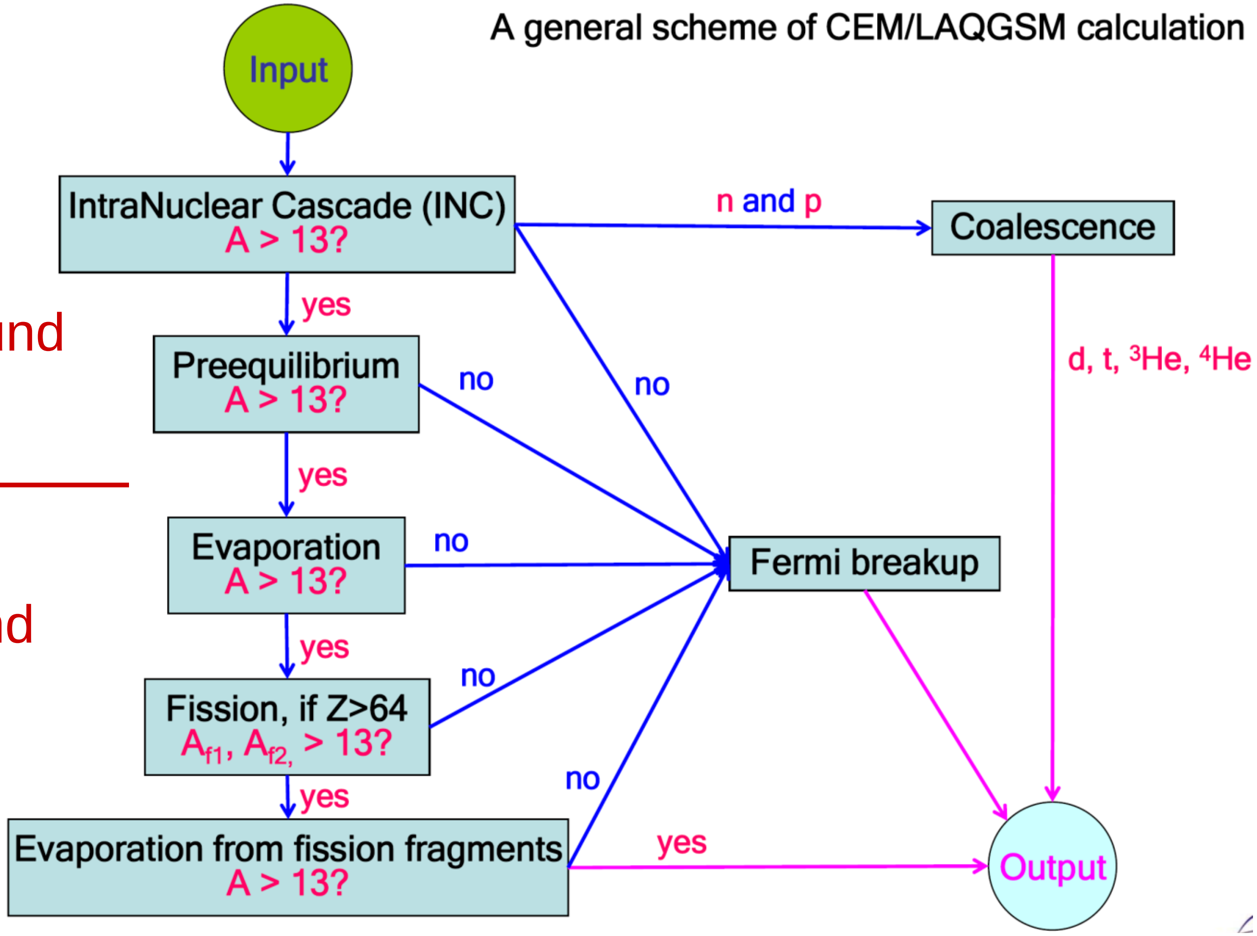
Evaporation | Precompound

Machner et al., Phys. Rev. C 73 (2006) 044606.

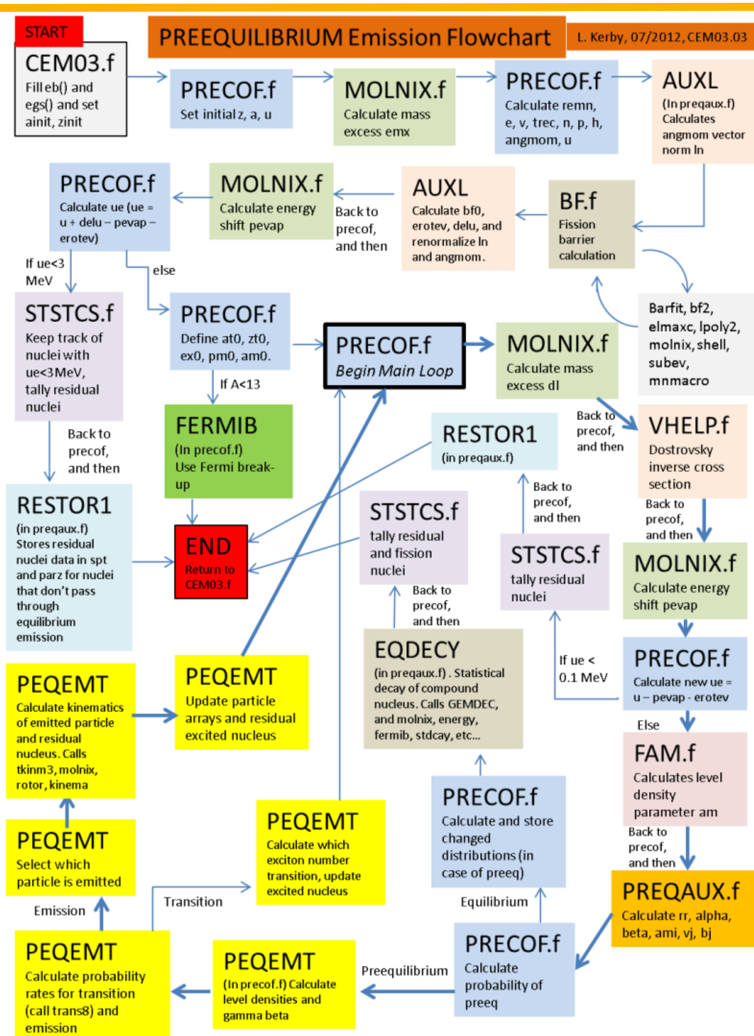
Overview of CEM Model

Precompound

Compound



Flowchart for Preequilibrium Code



Most of my work has been concentrated in the Precof, Peqemt, and Preqaux routines

Modified Exciton Model of Preequilibrium Emission

The Modified Exciton Model (MEM) used by CEM[5] calculates Γ_j, the emission width (or probability of emitting particle fragment j) as

$$\Gamma_j(p,h,E) = \int_{V_j^c}^{E-B_j} \lambda_c^j(p,h,E,T)dT \qquad (1)$$

where the partial transmission probabilities, λ_c^j, are equal to

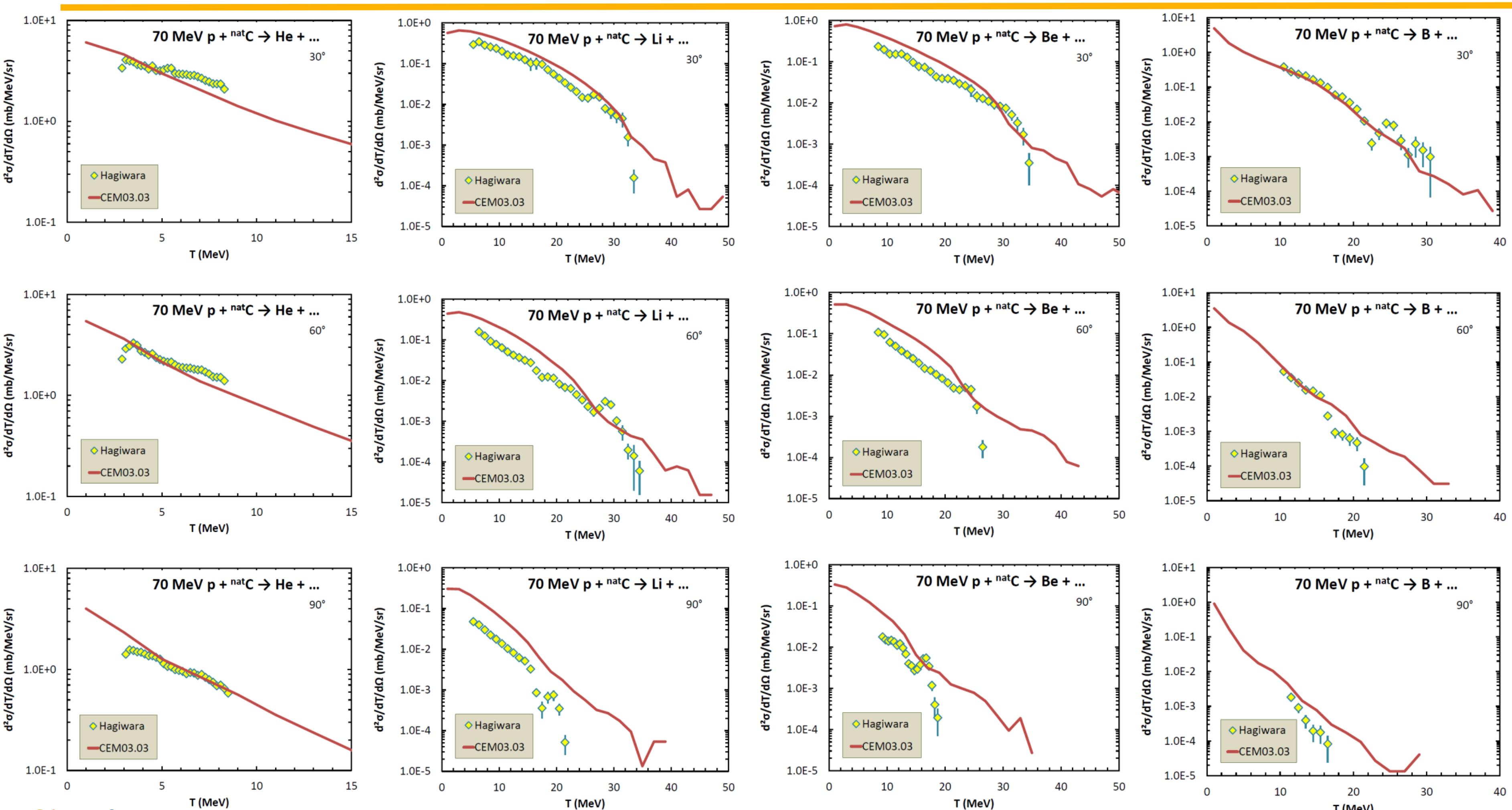
$$\lambda_c^j(p,h,E,T) = \frac{2s_j+1}{\pi^2\hbar^3}\mu_j \Re(p,h)\frac{\omega(p-1,h,E-B_j-T)}{\omega(p,h,E)}T\sigma_{inv}(T) \qquad (2)$$

For complex particles, an extra factor γ_j is introduced:

$$\gamma_j \approx p_j^3(\frac{p_j}{A})^{p_j-1} \qquad (3)$$

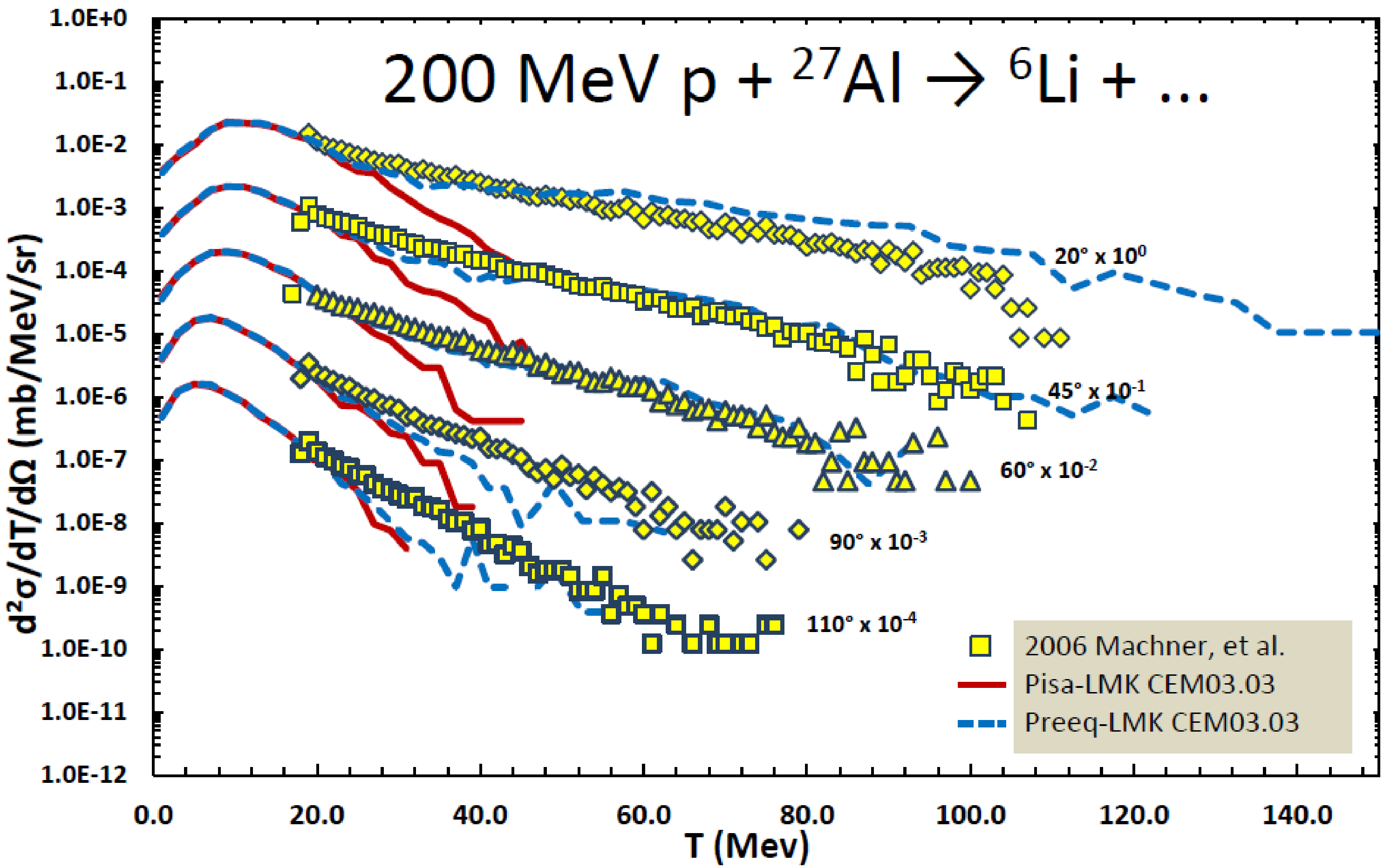
[5] K. K. Gudima, S. G. Mashnik, and V. D. Toneev, "Cascade-Exciton Model of Nuclear Reactions," Nuclear Phys. A401 (1983) 329-361.

Comparison with Hagiwara, et al.[6]



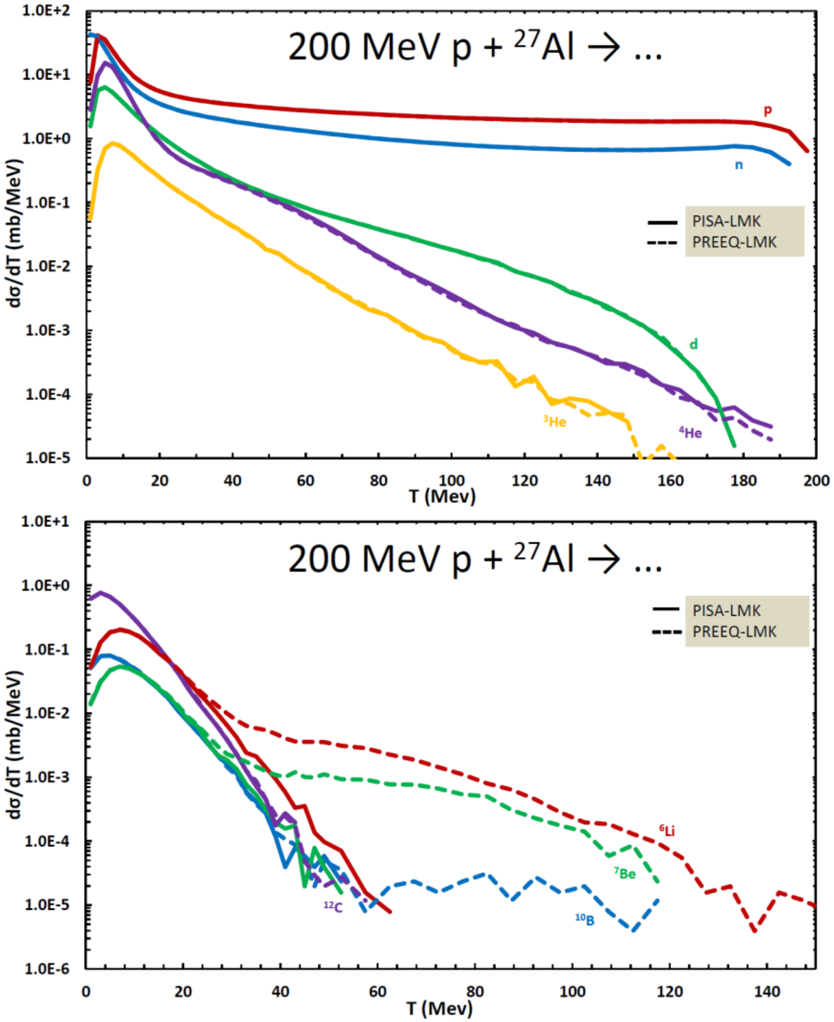
[6]Hagiwara et al, “Differential cross sections on fragments (2≤Z≤9) production for carbon, aluminum, silicon induced by tens-of0MeV protons”, Journal of Nuclear Science and Technology Vol. 49, No. 6 (2012) 571-587.

Preliminary Results



Machner et al., Phys. Rev. C 73 (2006) 044606.

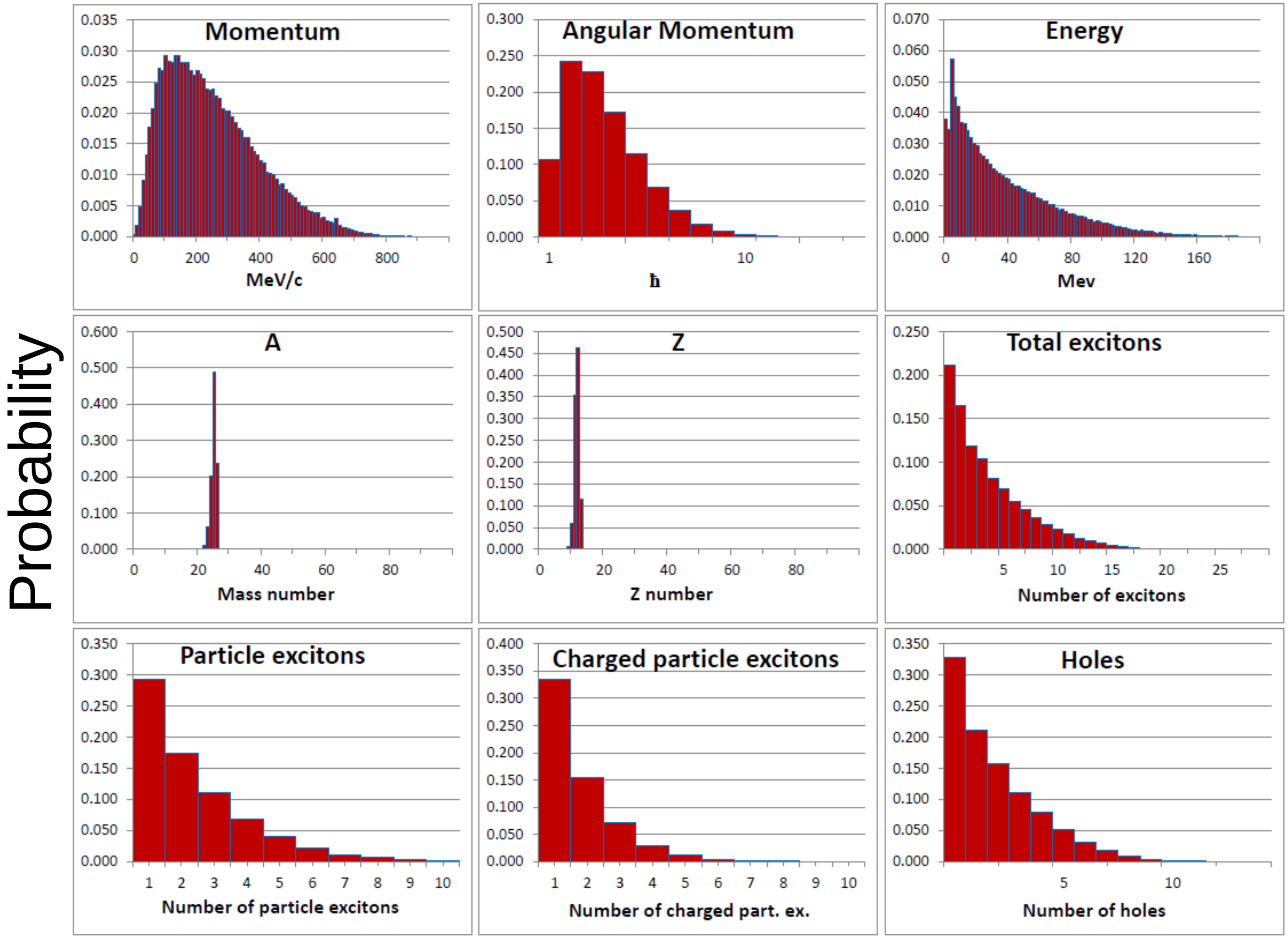
Angle-integrated Cross Section



High-energy tails of light fragments obtained without destroying established cross sections.

200 MeV p + ^{27}Al (after INC)

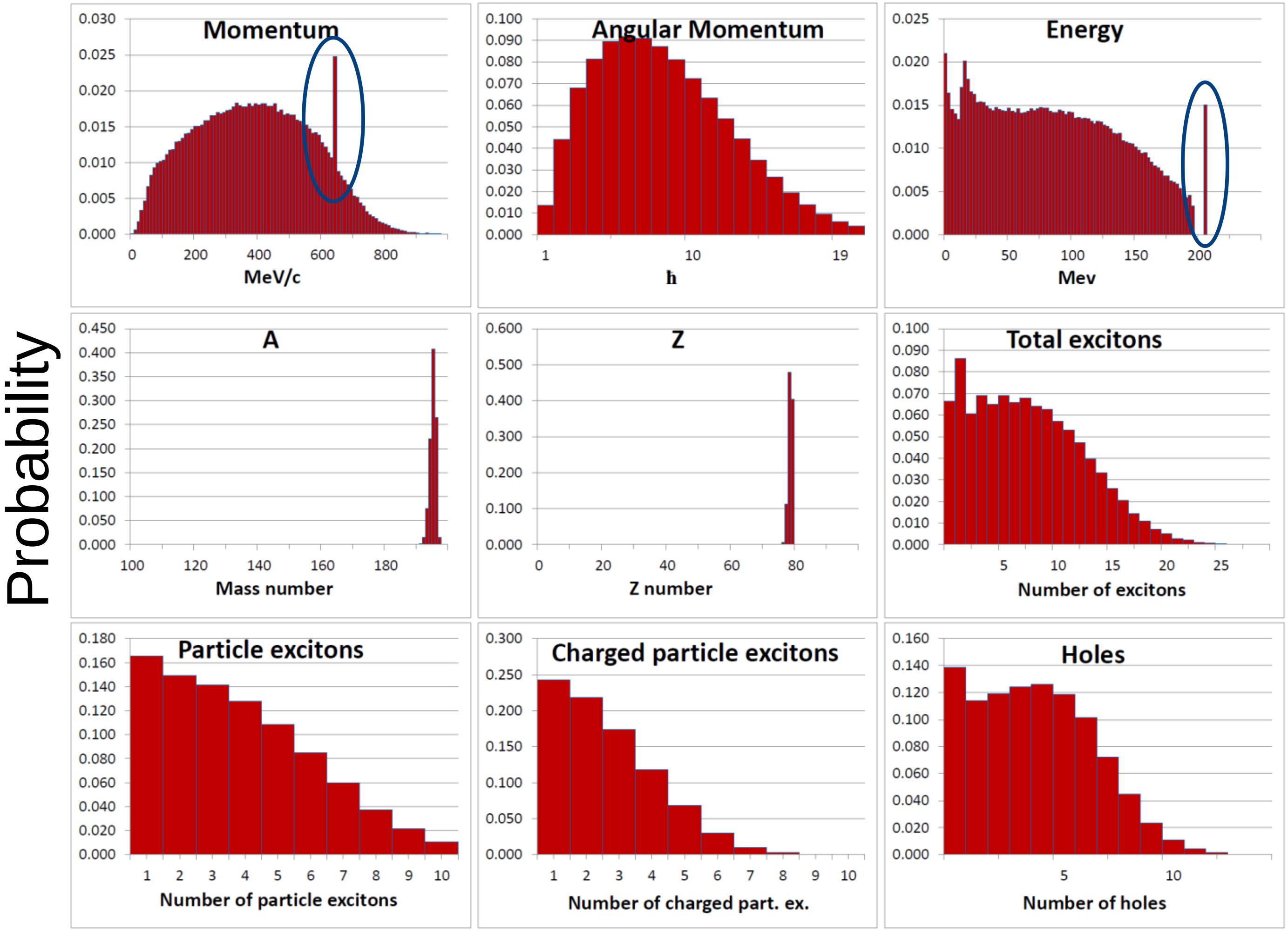
Residual Nuclei
After INC



200 MeV p + ^{197}Au (after INC)

Residual Nuclei

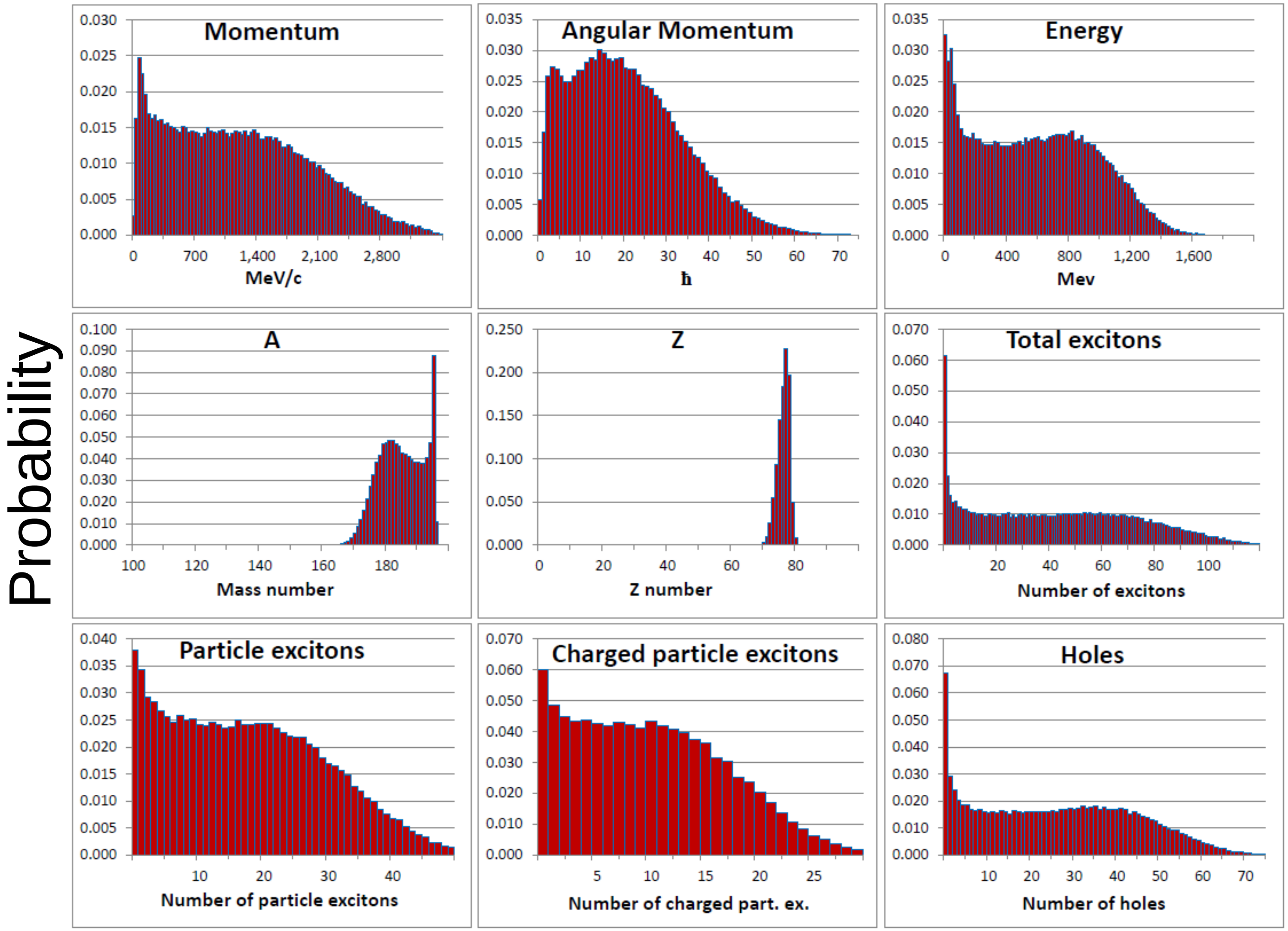
After INC



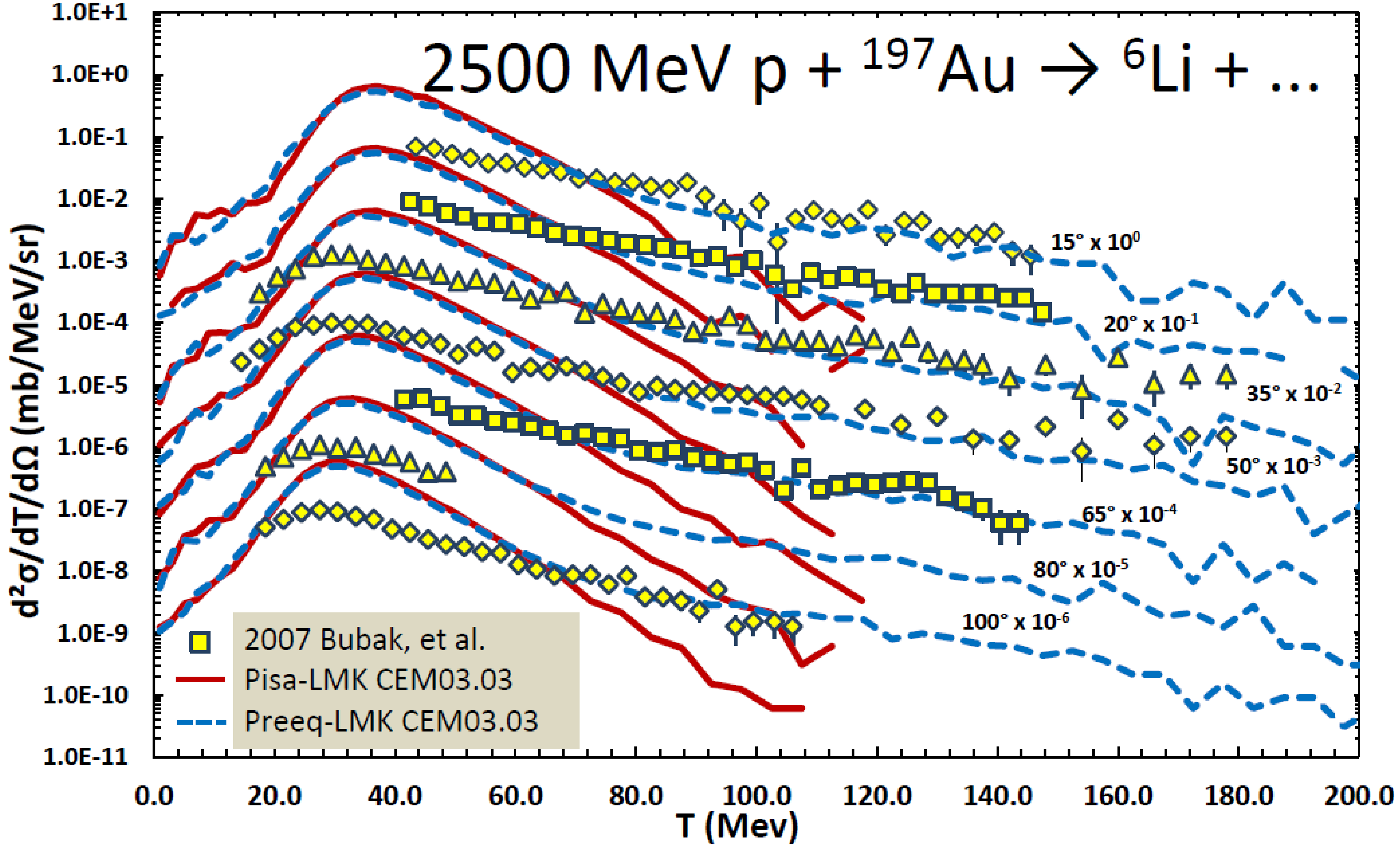
2500 MeV p + ^{197}Au (after INC)

Residual Nuclei

After INC



More Preliminary Results



Bubak et al., Physical Review, Part C, Nuclear Physics Vol.76 (2007) 014618.

Summary

CEM Extension

- Extended CEM to include emission of light fragments heavier than ^{4}He in the preequilibrium stage
- Added a subroutine to print the spectra of light fragments, according to isotope, mass number, or Z number
- Built a module to calculate residual nuclei physical properties, which can be inserted anywhere in the reaction process we want

Bugs

- Several bugs were encountered and fixed

Results

- Preliminary results show much greater ability to describe high-energy tails of LF

Future Work

- Parameterize γ_{β}, investigate coalescence and Fermi break-up. Upgrade evaporation model

Thank you for your attention!

PISA—Tally and Print Spectra Routine